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# SOME EFFECTS OF CONSTRUCTION ON THE LAUNDERING SHRINKAGE OF WOOL FABRICS



by
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# SOME EFFECTS OF CONSTRUCTION ON THE LAUNDERING SHRINKAGE OF WOOL FABRICS

By

Herman Bogaty, Louis I. Weiner, Arnold M. Sookne,
Mary L. Cozart and Milton Harris

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This work constitutes a part of the Army Quartermaster program on shrink-resistant wool, which is under the supervision of the National Research Council Advisory Committee on Textile Finishing Research.

## FOREWORD

The research and development program of the Quartermaster Laboratories on the shrink resistance of wool has culminated in the adoption of specification requirements for chemical or resin treatment of practically all of the military wool items that are subjected to laundering during normal usage in the field. This has resulted in a phenomenal improvement in the performance of these items with savings amounting to many millions of dollars as a result of the decreased necessity for replacement because of shrinkage.

During the course of this program it was noted that the geometry of the fabric as well as the basic fiber properties influenced the felting rate to a considerable degree. This was especially true in the case of knit fabrics, where it was found that proper determination of yarn twist, yarn size and tightness of knit of a treated fabric reduced the felting beyond the point achieved by the chlorination or resin treatment alone. Application of these findings to our specifications has resulted in still further improvement in the performance of wool knit goods purchased by the Quartermaster Corps.

Recent extension of this work to include woven fabrics has revealed that the geometry of the structure affects the felting shrinkage of these materials as much as it does that of knit fabrics. This report summarizes the results of some studies made on a series of woven fabrics varying in weave, texture, yarn twist, count and ply which may have considerable practical value in the design of fabrics for shrink resistant applications. Simple laboratory tests such as air permeability and flexural rigidity, which are related to tightness of structure, are shown to be useful measures of the relative resistance to felting of woven fabrics.

The work described in this report represents a joint effort of the Harris Research Laboratories in Washington, D. C., working under contract to the Quartermaster Corps, and the Quartermaster Research and Development Laboratories in Philadelphia, Pa. The report was prepared by Mr. H. Bogaty, Mr. A. Sookne, Miss M. L. Cozart and Dr. M. Harris of the Harris Research Laboratories and Mr. L. I. Weiner of the Quartermaster Laboratories. Appreciation is expressed to Mr. Ira Schwartz of Nathan Schwartz and Sons under whose supervision the yarns for this experiment were spun.

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## ABSTRACT

Studies were made of the effect of structural variables on the felting shrinkage of woven wool fabrics. Factors analyzed such as yarn count and texture revealed the importance of tightening the fabric structure as a means of reducing potential laundering shrinkage. Use of the "cover factor" computation, as defined by Peirce, provided a useful measure of the tightness of structure which could be correlated with shrinkage. Other measures of the tightness of fabric structure, such as air permeability and fabric rigidity, were also useful in predicting the potential shrinkage of these fabrics. Other structural parameters studied were yarn twist and weave. Yarn twist was found to have a significant effect on felting shrinkage and plain woven fabrics showed greater felting resistance than various twill weaves of similar texture.

## INTRODUCTION

Tight, firm structures are generally known to exhibit better dimensional stability in laundering than loose, sleazy materials. The work of Dutton[1,2] was the first to consider a quantitative approach to definition of "tightness" and its effect on the shrinkage of knitted fabrics. Recent studies in these laboratories[3] have shown that, entirely aside from the application of a shrink-resistant treatment, appreciable improvement in the laundering ability of knitted woolens may be achieved by increasing the number of stitches per inch or by increasing the weight of the yarns employed. Thus, the density with which the wool was packed into a given area was found to be the chief factor contributing to the resistance to felting. A small improvement in this direction was also found with the use of higher twist yarns.

It was considered desirable to extend this type of study to woven fabrics as well, in order to obtain some quantitative estimate of the influence of variables of construction on felting in laundering, since such data would have considerable practical utility in the design of fabrics. It was also believed that with woven materials, a wider range of each of the variables could be investigated than was possible in the experiments with knit goods.

Since in the previous study of knitted constructions it was found possible to define the tightness for a variety of fabrics in terms of a "cover factor," the relationship between cover factor and feltability of the present fabrics was investigated. A study was also made to determine whether air permeability and fabric rigidity measurements could be used in specifying the compactness of a fabric with respect to feltability.

## MATERIALS AND METHODS

A series of 18 fabrics was hand loomed from 7 basic commercial yarns, the nominal constructions of which are given in Table I. The fabrics were quite uniform in appearance and were comparable to similar commercially woven materials. The details of construction will be given subsequently in the appropriate sections together with the results of measurements of other fabric properties.

TABLE I

YARNS USED IN WEAVING EXPERIMENTS

| Code | Nominal Yarn No. | Nominal Twist Single tpi | Nominal Twist Ply tpi |
|---|---|---|---|
| 1 | 2/12 | 9.3 Z | 6 S |
| 2 | 2/12 | 5.9 Z | 6 S |
| 3 | 2/12 | 14.3 Z | 6 S |
| 4 | 1/6 | 6.6 Z | - |
| 5 | 2/7.5 | 7.5 Z | 5 S |
| 6 | 2/4.2 | 5.5 Z | 3.75 S |
| 7 | 1/6 | 6.6 S | - |

Laundering tests were made after relaxation of the fabrics in warm water for 1 hour, hydroextraction and air drying. Two successive severe launderings, each comprising a 30-minute washing period at 100 deg. F. with low titer soap as detergent and two 3-minute rinses were used.

The flexibility of each fabric was estimated by measuring its flexural rigidity by the hanging heart method of Peirce(4); a brief description of this method and the appropriate calculations are given by Taylor(5).

Air permeability was measured with the Schiefer device(6) at a pressure drop of 0.5 inch of water. The cover factor, K, was calculated from the relationship: $K = \frac{t}{\sqrt{Y}}$,

where $t$ is the number of threads per inch and Y is the effective yarn number. The sum of the warp and filling cover factors is used hereafter as the measure of tightness.

## RESULTS AND DISCUSSION

In order to facilitate comparisons, each factor of construction is isolated where possible and the results presented separately.

1 - Effect of fabric texture.

Three plain-woven fabrics were made from identical yarns, varying only the number of ends per inch. The results presented in Table II indicate that substantial increases in felting in

TABLE II

FELTING SHRINKAGE OF PLAIN WOVEN FABRICS IN WHICH NUMBER OF ENDS IS VARIED

| Fabric | Yarn No.[a] | Yarn Twist[a] Single tpi | Yarn Twist[a] Ply tpi | Fabric Weight oz./yd.$^2$ | Fabric Texture Warp yarns per in. | Fabric Texture Filling yarns per in. | Area Laundering Shrinkage percent |
|---|---|---|---|---|---|---|---|
| A | 2/11.1 | 9.2 Z | 5.6 S | 11.0 | 31 | 22 | 29 |
| B | 2/11.1 | 9.2 Z | 5.6 S | 9.9 | 31 | 16 | 39 |
| C | 2/11.1 | 9.2 Z | 5.6 S | 9.2 | 30 | 14 | 46 |

[a] Identical yarns used in warp and filling.

laundering occur as the texture is made more open. That is, increasing the weight through the use of more picks and ends should result in increased stability. This result is exactly analogous to that found for the knitted constructions in which knitting stiffness (texture) was found to be the most important variable of construction contributing to laundering stability. A similar result has been obtained by Johnson(7) with respect to the effect of fabric texture on the milling of woolen fabrics in fulling stocks. While exact correspondence between fulling and felting shrinkage in laundering can hardly be expected, it appears that the influence of fabric texture is at least qualitatively similar in these two types of felting.

2 - Effect of yarn twist.

The effect of yarn twist on shrinkage of similar fabrics in laundering is shown in Table III. The results indicate a conspicuous improvement in stability to laundering as the **singles**

TABLE III

FELTING SHRINKAGE OF PLAIN WOVEN FABRICS
IN WHICH YARN TWIST IS VARIED.

| Fabric | Fabric Texture: Warp yarns per in. | Fabric Texture: Filling yarns per in. | Fabric Weight oz/yd$^2$ | Yarn Number | Filling Yarn Twist: Singles tpi | Filling Yarn Twist: Ply tpi | Area Laundering Shrinkage percent |
|---|---|---|---|---|---|---|---|
| I | 32 | 26 | 10.5 | 2/11.4 | 5.9 Z | 5.2 S | 31 |
| A | 31 | 22 | 11.0 | 2/11.1 | 9.2 Z | 5.7 S | 29 |
| J | 31 | 25 | 10.9 | 2/11.4 | 15.0 Z | 5.7 S | 23 |

twist increases. Fabrics I and J are very closely comparable in all other respects, unequivocally showing the influence of the high-twist yarn in decreasing felting. Fabric A, despite its more open texture, felts somewhat less than fabric I, due to the higher yarn twist in the former. The effect of twist on laundering shrinkage of these woven fabrics is in the same sense as that previously reported for knitted fabrics. It appears, however, that moderately high twists are required to achieve this effect to any important degree.

3 - Effect of plying of yarns.

The felting of fabrics made with single-ply yarns is compared in Table IV with that of fabrics of similar weight and texture made with plied yarns. The data shown for samples PX and A indicate that shrinkage in laundering is similar for these fabrics irrespective of the ply of the yarns.

Another pair of fabrics was available, in which the fabric weights were similar and in which the total number of ends were virtually identical, samples M and C. However, one member of the pair, sample M, was balanced with respect to texture, and as shown in Table IV, this sample was significantly less feltable than sample C, which had many more yarns in the warp than in the filling direction. This unbalance is seen to affect the magnitude of the flexural rigidity, resulting in a low rigidity value in the direction corresponding to the smaller number of ends. This result suggested that the minimum, rather than the average value of flexural rigidity, could be correlated with the laundering shrinkage of the fabric, a procedure which is discussed in a subsequent section of this paper.

## TABLE IV

THE EFFECT OF PLYING OF YARNS ON FELTING SHRINKAGE OF PLAIN WOVEN FABRICS

| Fabric | Fabric Texture | | | Fabric Weight | Yarn Number | | Area Laundering Shrinkage | Fabric Flexural Rigidity | |
|---|---|---|---|---|---|---|---|---|---|
| | Warp yarns per in. | Filling yarns per in. | Total yarns per in. | $oz/yd^2$ | Warp | Filling | percent | Warp g.cm. | Filling g.cm. |
| PX | 27 | 27 | 54 | 10.7 | 1/5.5 | 1/5.3 | 30 | .31 | .33 |
| A | 31 | 22 | 55 | 11.0 | 2/11.2 | 2/11.2 | 29 | .42 | .37 |
| M | 24 | 21 | 45 | 9.7 | 1/5.3 | 1/5.3 | 34 | .27 | .28 |
| C | 30 | 14 | 44 | 9.2 | 2/11.2 | 2/11.2 | 46 | .33 | .14 |

With respect to the role of plying, however, with other factors being equal, the use of plied yarns does not confer added shrink resistance to the cloth. This result is in agreement with the conclusions from the previous study of knitted fabrics(3).

4 - The effect of direction of twist of the yarns.

It is well established in the weaving art that the direction of twist of the yarns used will affect the appearance, fullness and density of the fabric. Thus, Haven(8) notes: "When ....... the yarns are of the same direction of twist, there is a little more tendency to compactness in the fabric than if one thread is of opposite twist from the other." Strong(9) observes that fabrics made with yarns twisted in opposite directions have a fuller feel and show higher air permeability. This arises from the fact that when yarns of similar direction of twist are used for warp and filling, the fibers on the top of the yarn and those on the under surface of a crossing yarn coincide in direction, the yarns "bedding" into one another and resulting in a flatter, more compact fabric. With yarns of opposing twist direction, the warp and filling yarns maintain their integrity to a greater extent, yielding a softer, fuller and more open cloth. One would expect, therefore, that the latter would be more feltable in laundering. An appropriate comparison of such fabrics is shown in Table V.

**TABLE V**

THE EFFECT OF DIRECTION OF TWIST OF THE YARNS ON FELTING SHRINKAGE OF 2/2 TWILL FABRICS.

| | Fabric Texture | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Warp | Filling | Yarn Number | | Yarn Twist | | Area Laundering | Air |
| Fabric | yarns per in. | yarns per in. | Warp | Filling | Warp tpi. | Filling tpi. | Shrinkage percent | Permeability $ft^3/min/ft^2$ |
| N | 25 | 27 | 1/5.3 | 1/5.3 | 5.3 S | 5.3 S | 41 | 150 |
| Q | 25 | 26 | 1/5.5 | 1/5.3 | 5.4 Z | 5.3 S | 48 | 190 |

Fabric Q, woven from yarns of opposing twist direction, is seen to shrink in laundering to a greater extent than sample N, woven from yarns of similar twist direction, the fabrics being otherwise nearly identical. These samples showed very little difference in flexural rigidity, but the relative compactness revealed by the air permeability measurements which are also given in Table V is in the direction predicted by Strong(9) and does seem to be correlated with the feltability.

5 - Effect of yarn number.

It was considered of interest to compare the felting properties of fabrics of similar textures but made from yarns differing in weight. The data previously given have shown that decreasing the weight through the use of fewer ends results in increased felting shrinkage; in this section a method of changing the fabric weight through use of different yarn weights but maintaining the texture is considered. The comparisons of two such pairs of fabrics is made in Table VI.

TABLE VI

EFFECT OF YARN NUMBER ON FELTING SHRINKAGE OF PLAIN WOVEN FABRICS OF SIMILAR TEXTURE

| Fabric | Fabric Texture: Warp yarns per in. | Fabric Texture: Filling yarns per in. | Yarn Number: Warp | Yarn Number: Filling | Fabric Weight oz/yd$^2$ | Air Permeability ft.$^3$/min./ft$^2$ | Area Laundering Shrinkage percent |
|---|---|---|---|---|---|---|---|
| B | 31 | 16 | 2/11.2 | 2/11.2 | 9.9 | 126 | 39 |
| L | 31 | 17 | 2/11.2 | 2/3.9 | 14.6 | 56 | 28 |
| A | 31 | 22 | 2/11.2 | 2/11.2 | 11.0 | 35 | 29 |
| K | 31 | 23 | 2/11.2 | 2/6.8 | 13.0 | 22 | 26 |

The data show that where a large difference in weight is produced by using heavier yarns, a pronounced reduction in felting results. In the comparison between fabrics A and K, the

differences in weight are smaller and the fabrics are relatively tight in texture, so that the resulting effect on felting, although in the proper direction, is very small in magnitude. The difference in air permeability values in these two cases also reflects the laundering behavior, being large where the differences in feltability are also large.

6 - Effect of type of weave.

Up to this point, consideration has been given to the influence of the yarn construction variables or of the number of yarns per unit area on the laundering shrinkage of fabrics. It is clear, however, that the manner in which the yarns are interlaced might be expected to affect the fabric feltability. Comparisons of the laundering behavior of fabrics of different weave but otherwise similar except as indicated are shown in Table VII.

TABLE VII

EFFECT OF TYPE OF WEAVE ON FELTING SHRINKAGE OF FABRICS

| Fabric | Fabric Texture: Warp yarns per in. | Fabric Texture: Filling yarns per in. | Weave | Weight per Sq.Yd. oz. | Area Laundering Shrinkage percent | Air Permeability $ft^3/min./ft^2$ |
|---|---|---|---|---|---|---|
| PX | 27 | 27 | Plain | 10.7 | 30 | 53 |
| Q | 25 | 26 | 2/2 broken twill | 10.6 | 48 | 190 |
| H | 32 | 34 | 3/1 unbalanced broken twill | 12.5 | 20 | 41 |
| E | 33 | 28 | 2/2 broken twill | 11.8 | 26 | 41 |
| F | 32 | 31 | 2/1 twill | 12.4 | 27 | 58 |
| D | 30 | 29 | 2/2 broken twill | 11.5 | 32 | 76 |
| A | 31 | 22 | Plain | 11.0 | 29 | 35 |

Of the various weaves tabulated, the plain woven fabric seems to be relatively felt resistant. Plain woven sample PX shrinks much less than does sample Q, a twill weave, although construction-wise the two fabrics are quite similar; the difference

in compactness between these two samples is revealed by the large difference in the air permeability values. The laundering stability of the plain weave can also be seen in comparing plain woven fabric A with the twilled fabrics, since sample A is similar to the twills in feltability despite its substantially lower thread count. One would expect that a fabric of such low thread count would be appreciably more feltable than the others in the group. That the plain weave sample A is as compact as the twills of tighter construction is shown by the similarity in air permeability.

The differences among the various twills with respect to shrinkage are not very great if the texture differences are taken into account. The air permeability measurements, however, do rate the twill fabrics in approximately the order of their laundering shrinkage.

The data of Johnson(7) bearing on the fulling of woolen fabrics embraced a wider variety of weaves than was available in this study. From his results it can be seen that the float length is an important factor in weave construction with respect to the degree of fulling; other things being equal, fabrics with long-float constructions felt more rapidly and to a greater extent in the fulling stocks. It is not unlikely that a similar but smaller effect might be found for felting in laundering if a wider variety of weaves were studied.

7 - Measures of fabric tightness.

The preceding discussion has suggested that the compactness of the fabric structure, whether due to the number or weight of the yarns or to the nature of their interlacing, is the factor which is basic to the feltability of the fabric. It was considered desirable to determine whether a single parameter could be used to describe this tightness or compactness factor. The present study suggests the possible use for this purpose of air permeability, of the flexural rigidity of the fabric, and of the cover factor, the last of which has frequently been used to describe fabric tightness. Table VIII summarizes the measurements of the fabrics with respect to these properties, and the relationships between felting shrinkage and cover factor, flexural rigidity and air permeability respectively are plotted in figures 1 through 3 respectively.

Since varying the number of ends or yarn number influences feltability, it is not surprising that the cover factor which

TABLE VIII

THE RELATIONSHIP BETWEEN SHRINKAGE IN LAUNDERING AND VARIOUS MEASURES OF FABRIC COMPACTNESS

| Fabric | Shrinkage in Laundering Warp % | Shrinkage in Laundering Filling % | Shrinkage in Laundering Area % | Cover Factor Warp | Cover Factor Filling | Cover Factor Sum | Flexural Rigidity Warp g.cm. | Flexural Rigidity Filling g.cm. | Air Permeability $ft^3/min./ft^2$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Plain Weaves | | | | | |
| J | 10 | 15 | 23 | 13.1 | 10.4 | 23.5 | 0.49 | .39 | 39 |
| K | 12 | 16 | 26 | 13.1 | 12.5 | 25.6 | .48 | 1.05 | 22 |
| L | 10 | 20 | 28 | 13.1 | 12.0 | 25.1 | .39 | 1.17 | 56 |
| A | 12 | 19 | 29 | 13.1 | 9.3 | 22.4 | .42 | .37 | 35 |
| PX | 16 | 16 | 30 | 11.6 | 11.6 | 23.2 | .31 | .33 | 53 |
| I | 15 | 19 | 31 | 13.6 | 10.8 | 24.4 | .46 | .51 | 21 |
| M | 17 | 21 | 34 | 10.4 | 9.1 | 19.5 | .27 | .28 | 170 |
| P | 18 | 21 | 35 | 10.4 | 10.4 | 20.8 | .27 | .25 | 160 |
| B | 19 | 25 | 39 | 13.1 | 6.8 | 19.9 | .37 | .19 | 130 |
| C | 24 | 29 | 46 | 12.7 | 5.9 | 18.6 | .33 | .14 | 180 |
| | | | | Twill Weaves | | | | | |
| H | 9 | 12 | 20 | 13.6 | 13.1 | 26.7 | .42 | .44 | 41 |
| E | 15 | 13 | 26 | 14.0 | 11.9 | 25.9 | .44 | .32 | 41 |
| F | 14 | 15 | 27 | 13.6 | 13.1 | 26.7 | .43 | .41 | 58 |
| G | 18 | 16 | 31 | 10.6 | 13.1 | 23.7 | .52 | .38 | 71 |
| D | 17 | 18 | 32 | 12.7 | 12.3 | 25.0 | .41 | .34 | 76 |
| N | 23 | 23 | 41 | 10.8 | 11.6 | 22.4 | .27 | .30 | 150 |
| O | 25 | 23 | 42 | 10.8 | 12.9 | 23.7 | .29 | .31 | 150 |
| Q | 26 | 30 | 48 | 10.8 | 11.2 | 22.0 | .28 | .29 | 190 |

Fig. I
THE RELATIONSHIP BETWEEN FELTING SHRINKAGE & COVER FACTOR OF PLAIN & TWILL WOVEN FABRICS

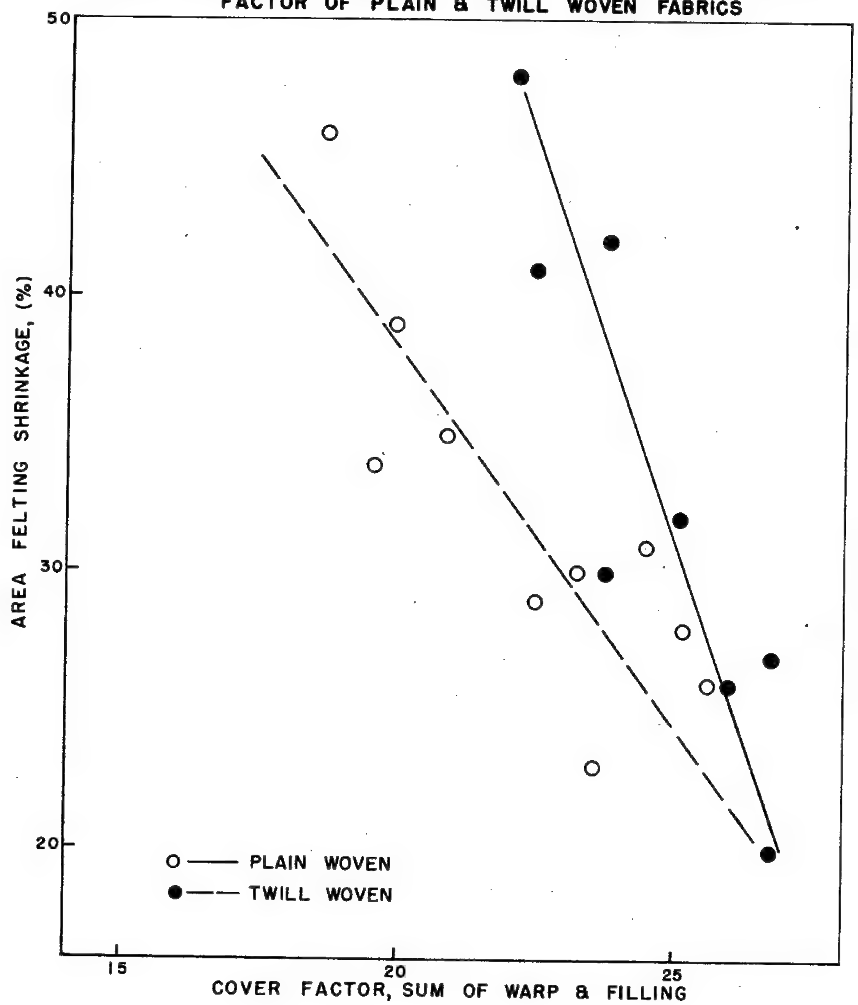
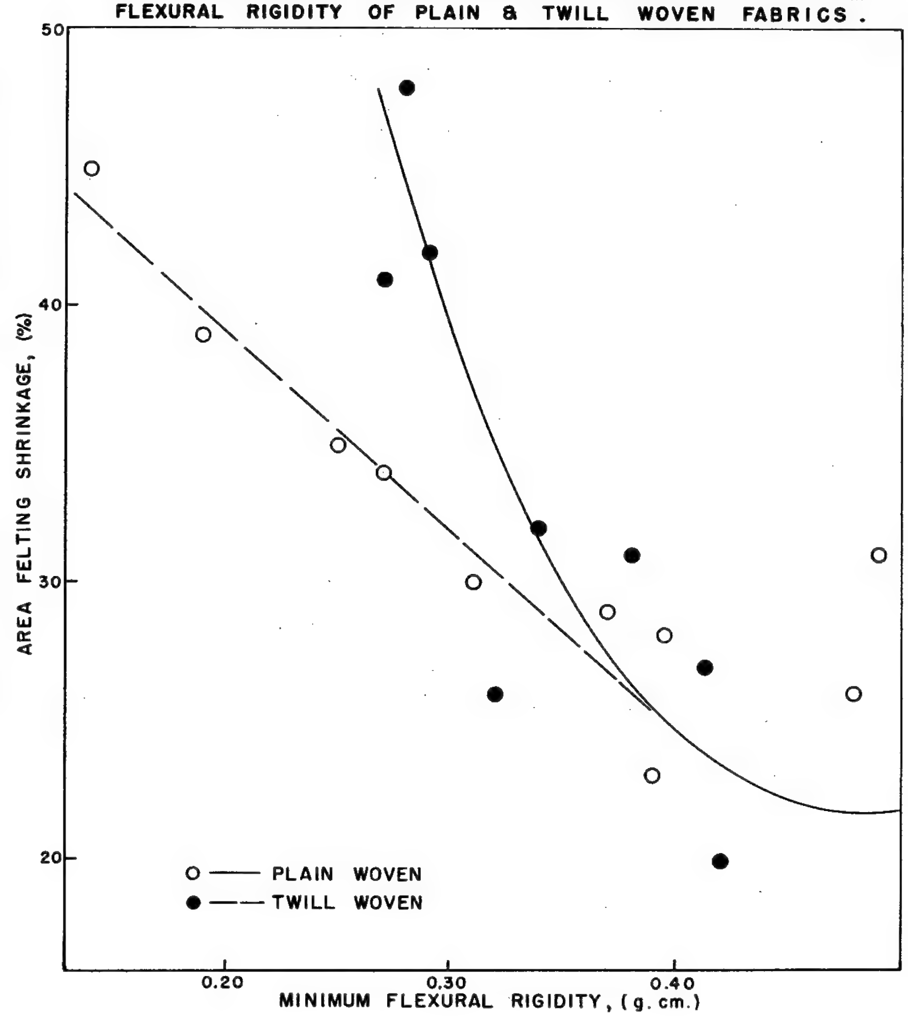



Fig. 2
THE RELATIONSHIP BETWEEN FELTING SHRINKAGE & MINIMUM FLEXURAL RIGIDITY OF PLAIN & TWILL WOVEN FABRICS.



is calculated from these construction variables is also related to the shrinkage in laundering. The graph shown in Figure 1, plotting shrinkage as a function of cover factor, indicates a satisfactory overall relationship. The difference between these two curves suggests that for a given amount of yarn cover twills are more easily felted than plain woven fabrics. This is a reasonable result in view of the greater float length in twills, and consequently the longer segment of yarn between tie-down points. This result is in agreement with the previous discussion on the effect of weave.

The flexural rigidity of the fabrics is also affected by a number of the same elements as cover factor, and Peirce[10] has noted that as the cover factor of a fabric increases, it becomes increasingly stiff and hard. The inverse relationship between laundering shrinkage and flexural rigidity for the present fabrics is plotted in Figure 2. The lower value of rigidity was used in each case irrespective of whether it appeared in the warp and filling, this procedure being suggested by the data given previously.

The curves in Figure 2 describe a generally satisfactory relationship for these samples between felting behavior and ease of deformation of the fabric. This figure again demonstrates the relatively high feltability of twills compared to plain woven fabrics, the shrinkage rigidity curves for the twills falling appreciably above those for the plain-weave fabrics.

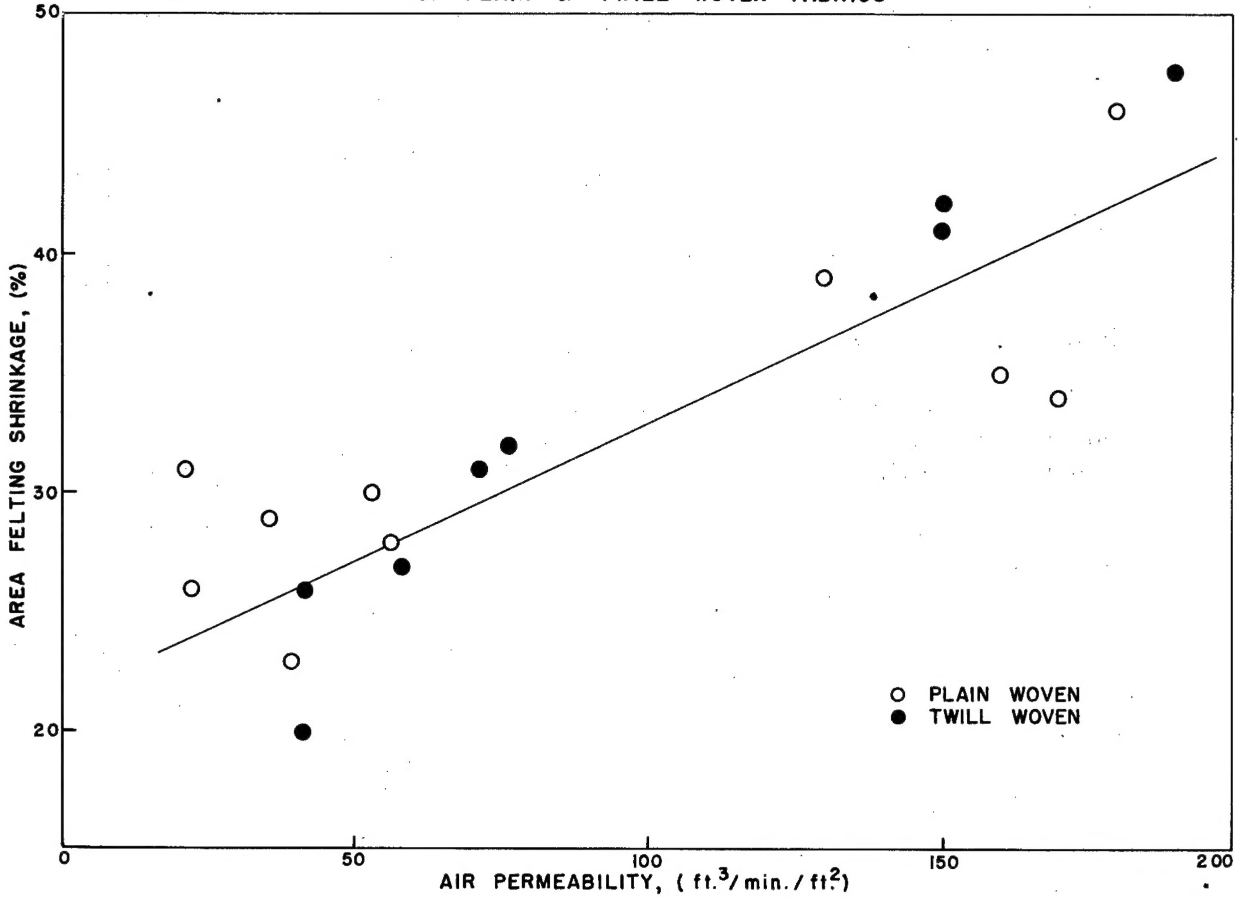
The relationship between the felting shrinkage and the air permeability of the various fabrics is plotted in Figure 3. The air permeability, which describes the fabric compactness, shows a fairly good relationship to laundering shrinkage.

Each of these parameters cover factor, flexural rigidity and air permeability appears to be related to the feltability of a fabric and may be considered to be a measure of fabric tightness. Cover factor and flexural rigidity of the fabric are interdependent to some extent and their magnitudes are affected by the yarn diameter and the number of yarns present.

When the yarns are interlaced in different ways, however, as by variation in weave or in twist direction of the yarns, the difference in construction of the resulting fabric may not be revealed by cover factor or rigidity measurements. In such cases, air permeability may be used as a measure of the compactness with respect to felting.

The case in which the amount of twist in the yarn influences feltability differs from those just discussed, in that the use of

Fig. 3
THE RELATIONSHIP BETWEEN FELTING SHRINKAGE & AIR PERMEABILITY
OF PLAIN & TWILL WOVEN FABRICS




high twist yarns decreases shrinkage in spite of the fact that such fabrics are more open. Fiber migration is hindered in the high twist yarn so that feltability is lower in spite of the apparent openness of the fabric.

Since it is generally agreed that felting occurs as a result of the tendency of the individual fibers to migrate with relation to one another, the reasons for the various construction factors operating as the way they do are clear. For a given amount of relative fiber movement, high values of yarn twist and the use of weaves in which the yarns are bound at frequent intervals by the cross yarns obviously will require the input of more energy in the laundering operation to overcome the higher frictional forces. Similarly, in situations in which there are many fibers per unit area, the normal forces exerted on each fiber

are relatively large, again resulting in increased frictional forces between fibers.

## SUMMARY AND CONCLUSIONS

1. Greater stability to felting shrinkage in woven fabrics may be achieved through the use of a larger number of ends per inch, higher twist yarns and heavier yarns (lower yarn number).

2. The use of plied yarns, other things being equal, does not appear to confer added shrink resistance to a fabric.

3. A fabric woven with warp and filling yarns of opposite twist direction felts to a greater extent than one in which the yarns are of the same direction of twist.

4. Plain woven fabrics show greater felt resistance than various twill weaves of similar texture.

5. In general, the relative feltability of a fabric is determined by its compactness; appropriate measures of the latter for this purpose are cover factor, flexural rigidity and air permeability.

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